Defining the state of the art in Biomedical imaging: Research needs for the future

Opening remarks

Harrison H. Barrett

University of Arizona

Biomedical Imaging: Art or science?

- Is there a science of imaging?

- What are the major open questions?

- What is needed to answer them?

Elements of a science

- Common language, agreed-upon set of definitions

- Accepted set of experimental procedures

- Theory with predictive value

Is there a theory with predictive value in image science?

- Yes, if the goal is to predict the image.
  - Theories of propagation of radiation
  - Theories of radiation detection

- Not so obvious if the goal is to predict the *usefulness* of the image.

The essential question:

How does one define, measure and predict image quality?

Any scientific definition of image quality must address four key questions:

- What information is desired from the image?
- How will that information be extracted?
- What objects will be imaged?
- What limits the information extraction?

Objective (task-based) assessment of image quality

- Task

- Observer

- Object statistics

- Image statistics

Each component leads to a set of open questions and opportunities for research in image science.

Tasks

- Classification
  - Diagnosis
  - Signal detection
  - Image segmentation

- Estimation
  - Quantitation of physiological parameters
  - Estimation of features for pattern recognition
  - Image reconstruction

Some research questions related to task specification

- How does one choose the task?
- Can the task be defined too narrowly?
- How does task performance depend on object parameters (e.g., tumor size)?
- How does performance on classification tasks relate to that on estimation tasks?
- Can one compare different imaging modalities on the basis of a common task?
- How can information from different modalities be combined towards performance of a single task?

Observers

- Humans

- Mathematical models that predict human performance on specific tasks

- Ideal observers that determine the maximum possible performance

- Machine algorithms (CAD)

Research directions related to observers

- Psychophysical methodology
- Measurement and modeling of human perception with medical images
- Theoretical and computational issues related to ideal observers
- Choice of features and classifiers in CAD

Object statistics

- Gross anatomy and its variability from patient to patient

- Smaller-scale anatomical variations

- Random physiological function

- Random distribution of tracers or contrast agents

Research directions related to object statistics

- Mathematical and physical phantoms
- Statistical descriptions specific to one modality – or common to many?
- Low-dimensional descriptions of infinite-dimensional probability densities
- Estimation of parameters in statistical descriptions – relating the models to reality
- Can we model and optimize the characteristics of a contrast agent?

Image statistics

- Poisson noise

- Electronic noise (usually Gaussian)

- Internal sensor noise (e.g. multiplication processes in x-ray detectors)

- Object statistics as propagated to the image

Research questions related to image statistics

- What are the appropriate statistical descriptions of image noise?

- How do the sensor statistics relate to task performance? When do anatomical variations dominate?

- How can one optimize the sensor parameters? How do the characteristics of the sensor and image-forming elements influence the effect of object variations on image statistics? On task performance?

Some crucial areas for research

- Systematic evaluation and optimization of image-forming elements and image sensors

- Evaluation of targeted agents with respect to specific medical tasks and observers

- Optimization of image reconstruction and interpretation strategies

- Identification of technological impediments to task performance and development of novel approaches to overcoming them

Some not-so-obvious areas that NIBIB should support

- Human visual perception
- Psychophysical methodology
- Statistical models of objects and images
- The mathematics of image formation and image reconstruction
- Basic research in statistical decision theory
- New approaches to data acquisition and storage

A challenge to workshop participants

Think beyond the art, the technology

Identify the open scientific questions in your area

Find ways in which the research community can address these questions with NIBIB support and produce imaging systems with objectively improved performance